SOURCE, NATURE AND SYMPTOMOLOGY OF INDOOR AIR POLLUTANTS

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INTRODUCTION

ACVA Atlantic Inc. specializes in the study of indoor air pollution. Since we established ACVA in 1981, we have pioneered a multi-disciplined approach to the investigation of internal pollution. Investigators include chemists, microbiologists, and air conditioning engineers -- three disciplines unused to working as a team. Our client list includes numerous government agencies; multi-national companies in insurance, finance, industry, banking, and property management; colleges, schools, and numerous hospitals. Most of our clients now not only ask us to examine other buildings that they own, but also enter into long term contracts of regular monitoring and preventive maintenance. In fact, as of March 1988, we have now studied the indoor air quality of over 42 million square feet of property.

INDOOR POLLUTANTS - THE SOURCES

Virtually everything we use in the interior sheds some particulates and/or gases. When a building is new, some compounds are given off quickly and soon disappear. Others continue "off-gassing" at a slow pace for years. Common office supplies and equipment have been found to release dangerous chemicals-especially duplicators and copiers and we have even found formaldehyde being released from bulk paper stores.

People themselves are a major contributor since each person sheds literally millions of particles, primarily skin scales, per minute. Many of these scales carry microbes but fortunately the vast bulk of these microbes are short lived and harmless.

Clothing, furnishings, draperies, carpets, etc. contribute fibers and other fragments. Cleaning processes, sweeping, vacuuming, dusting, etc. normally remove the larger particles, but often increase the airborne concentrations of the smaller particles. Cooking, broiling, grilling, gas and oil burning, smoking, coal and wood fires also generated vast numbers of airborne particulates, vapors, and gases. If the windows and doors are closed all of these can only accumulate in that internal environment.

INDOOR POLLUTANTS -- THE TYPES

There are many types of indoor pollutants, gases, vapors, dusts, fibers, and viable and non-viable microorganisms. Some of the more common ones are described below.

Organic Chemicals

There are arguably the widest range of pollutants with literally thousands of specific types fortunately occurring in very dilute concentrations which are usually expressed as parts per million or per billion. Most of these are presumed to be safe at the very low levels encountered, although some synergism between different organics or some incidences of organics "sensitizing" people to other pollutants cannot be ruled out. Usually the organics are more a problem in the typical home than the office and concentrations in the home are usually higher than the office mainly due to lower air exchange rates.

Radon Gas

Radon, a decay product of uranium, is present in variable quantities in soils. It moves from the soil by diffusion into the soil's air pockets or into soil water. Then the radon can migrate from the soil air through unvented crawl spaces, building foundation cracks, etc. into the indoor space. Some building aggregates, cinder block, etc. also contain radon and out-gassing from these materials add to the indoor air levels. In other cases radon enters a building via the water supply. Some of this radon is released when there is turbulence of the water such as a running tap. It has been estimated by some researchers that anywhere from 10 to 15% of the average radon we are exposed to comes from such water. However, the general consensus is that the principal source of radon in buildings undoubtedly is the soil gas. Pollution by radon is far more prevalent in homes than in offices, again mainly due to the lower air exchange rates in homes plus the fact that homes have a larger area of exposure to soil relative to building volume and soil leakage area.

Inorganic Oxides

Carbon dioxide is produced by respiration and combustion, oxides of nitrogen and sulphur are combustion products associated with gas stoves, wood, coal fires, and kerosene heaters. Carbon monoxide is emitted from unvented kerosene heaters or wood stoves and it frequently diffuses into buildings from automobile exhaust fumes generated in adjacent garages. Small to trace quantities of each of these gases and other organics are present in cigarette smoke.

Ozone is another gas that is generated, usually in very small quantities, by miscellaneous copying machines and by certain electrostatic precipitators that are used to clean up the air. In one specific case that we studied, the maintenance staff of a building switched off the main air supply fans over the weekend, but omitted to switch off the central electrostatic precipitators. Thus, ozone accumulated inside the air handlers and was subsequently delivered to the staff first thing each Monday morning. When the fans were switched on this caused a severe, though temporary, period of discomfort to the people working in the areas involved.

FIBERS

Asbestos

Prior to 1973, asbestos was the material of choice for fire-proofing, thermal insulation, and sound insulation. It was used as a spray-on insulation of ceilings and steel girders; as a thermal insulation of boilers, pipes, ducts, air conditioning units, etc.; as an abrasion resistant filler in floor tiles, vinyl sheet floor coverings, roofing, and siding shingles; as a flexible, though resistant, joining compound and filler of textured paints and gaskets; as a bulking material with the best wear characteristics for

automobile brake shoes, and in countless domestic appliances such as toasters, broilers, dishwashers, refrigerators, ovens, clothes dryers, electric blankets, hair dryers, etc. In fact, the EPA has estimated that approximately 733,000 or 20% of all government, residential, and private non-residential buildings in the U.S. contain some type of friable asbestos-containing material.

The fact is that many asbestos bearing materials or products are of no health risk whatsoever when used in the normal course of events. However, if for any reason of wear, abrasion, friability, water damage, etc., any of the asbestos fibers are released into the air and inhaled into people's lungs, there is a health hazard. The scientific evaluation of all available human data provides no evidence for a "safe" level of airborne asbestos exposure, thus any quantity should be considered potentially dangerous.

Glass Fibers and Other Man-made Fibers

The glass fiber (usually referred to as fiberglass) industry is in its infancy compared with asbestos and since asbestos related illnesses only manifest themselves tens of years after exposure, there are some schools of thought that suggest glass fiber fragments will also accumulate in the lungs and cause later problems. This may be so, but it is unlikely to be anywhere near as severe. The fibers of glass are not shed in such large quantities as asbestos and most of the resins, etc. bonding the fibers together appear to be extremely effective and long lasting. However, some fragmentation does occur and this is especially noticeable when the loose fiberglass insulation, popularly used in attics and ceiling voids, is disturbed. Most of us have experienced itching on contact with fiberglass and dermatitis-type reactions are not infrequent due to airborne fiberglass particles.

MICROBES

In our reviews of the literature, the one area of indoor pollution that has received least study or research has been contamination due to microbes. Nine percent of the first 223 major buildings studied by ACVA have exhibited high levels of potentially pathogenic or allergy causing bacteria, including Actinomyces and Flavobacterium species. In addition, Legionella pneumophila, the cause of the dreaded Legionnaires' disease has frequently been isolated from inside air conditioning systems.

Perhaps more significantly, we have found over twenty-eight different species of fungus contaminating air handling systems (see Table 1).

Table 1. Fungi Isolated from Air Conditioning Systems by ACVA Systems -- 1981 to 1987

Alternaria sp.	Aspergillus sp.
Aureobasidium sp.	Candida sp.
Cephalosporium sp.	Chaetomium sp.
Chrysosporium sp.	Cladosporium sp.
Curvularia sp.	Diplosporium sp.
Fusarium sp.	Helminthosporium sp.
Monilia sitophila	Monosporium sp.
Mucor sp.	Mycelia sterila
Oospora sp.	Paecilomyces sp.
Penicillium sp.	Phoma sp.
Rhizopus sp.	Rhodotorula sp.
Saccharomyces sp.	Scopulariopsis sp.
Streptomyces sp.	Tricothecium sp.
Verticillium sp.	Yeasts

Of the 223 buildings studied by ACVA between 1981 and 1987, thirty-four percent have been found to contain high levels of potentially pathogenic or allergy causing fungi, including Alternaria, Aspergillus, Cladosporium, Fusarium, and Penicillium species. In many buildings with excessive staff complaints, either Aspergillus and/or Cladosporium species of fungus were found growing to excess in the air conditioning ductwork systems. In some investigations, epidemiological tests run by various doctors have confirmed severe allergic reactions to the spores of these fungi in all affected staff. Subsequent cleaning and removal of the sources of these fungal contaminants have resulted in a complete abatement of complaints.

DIRT IN DUCTWORK

HVAC systems also have been found to be poorly designed and negligently maintained. Excessive dirt accumulations are common in ductwork, even in hospitals. Frequently dirt is built into the systems during construction since the ducts are installed long before the windows, etc. and construction dusts from the site, plus wood shavings, lunch packets, coke and beer cans, etc. find themselves brushed into the vents then "out of sight -- out of mind." Thereafter over the life of the building, more dirt enters with the supply and return air. Good filters reduce the rate of this accumulation, but the only perfect filter would be a brick wall. All filters, even the ultra-efficient HEPA filters used in hospital operating rooms allow fine particles through. Many of these fine particles coalesce, sticking to each other by adhesion or electrostatic attraction and larger particles simply grow with time. In commercial buildings, much cheaper and far less efficient filters are common. Many will stop birds and moths, but that is about all. Occasionally we find that the filters have been omitted and very frequently we find they are undersize, resulting in large air gaps that allow massive volumes of air bypass to occur. Then, there are the large electrostatic precipitators that theoretically provide ultra-efficient air. In one major building we found 16 out of their 18 precipitators were inoperative due to broken parts, many had not worked for over a year. In a major hospital, we found the power pack was missing from one of these units. When inoperative electrostatic precipitators provide zero filtration.

Dirty ductwork is a prefect breeding ground for germs. It provides an enclosed space, constant temperature, humidity, and food -- which is the dirt. No germ could wish for more!

The extent of this potential problem is huge and it is very surprising what we have found in ducts. Dead insects, molds, fungi, dead birds and rodents are common. In 1984 we found two dead snakes in air supply ducts. We have also found rotting food, builders rubble, rags, and newspapers. All of these contaminate the air we breathe. It is the dirt that encourages germs to breed -- germs which cause infections.

The dirt and dusts also may be allergenic, in fact most of the dusts are, by definition, household dusts which are notorious for causing allergies in many people.

In a survey of a 750,000 square foot hospital in Virginia, we found 14 miles of ductwork. Here are a few examples of the problems we encountered in that maze of ducts. Smoke detectors blocked by dirt and inoperative; fire dampers jammed open by dirt -- they were unable to close; reheat coils completely blocked by dirt sealing off the fresh air supply; turning vanes and even the exhaust grilles completely sealed with dirt accumulations -- in the operating suite the exhaust fan was still working against these duct blockages causing such immense negative pressure in the ducts that the ducts were bowing inward almost to the point of collapse; huge excesses of bacteria and fungi were present inside the air handling chambers and throughout the ductwork; cross infection rates were high and nurses, doctors, and patients complained

about poor air quality. We have since cleaned all the air handlers and the 14 miles of ducts and have overseen the installation of more efficient filter systems. That hospital has been dramatically improved and its air quality is now well above average.

SYMPTOMOLOGY OF INDOOR AIR POLLUTANTS

In general, when one hears of a polluted building or a so-called "sick building," one hears familiar symptoms from occupants including eye and nose irritation, fatigue, coughing, rhinitis, nausea, headaches, sore throats, and general respiratory problems. Without doubt, the pollutant most often blamed for these symptoms by the public is environmental tobacco smoke (ETS). However, there are usually confounding variables presented by a number of potential contaminants that precludes a quick analysis establishing a single source of contamination. The main problem being the incredible similarity between symptoms from widely different irritants or even environmental conditions. For example, identical symptoms have been reported for individuals exposed to formaldehyde, ammonia, oxides of nitrogen, and ozone. In addition, similar symptoms are reported by those individuals suffering allergic type reactions to numerous dusts and to microbial spores such as Aspergillus, Penicillium, and Cladosporium fungi, among others. Similar symptoms have been reported from exposure to cotton dust and fiberglass fragments and an ever increasing and similar problem is encountered due to low relative humidities. The latter is well known to frequent flyers of airliners where relative humidity levels are frequently as low as 10%, compared to a normal lower comfort level of say 40%.

This similarity of symptoms is usually unappreciated by the public and in part it accounts for a bias against tobacco smoke, which happens to be the sole visible air pollutant. Furthermore, due to their unreliability, we, as a policy, refuse to rely upon or otherwise use the information generated by subjective building occupant questionnaires. Only upon careful investigation of the entire indoor environment and ventilation system of a building can be draw informed conclusions about the various causes of poor indoor air quality. As a result, we have made it our business to perform precisely such investigations. Despite being the main suspect of the occupants in many of the buildings we have examined, we have determined high levels of environmental tobacco smoke to be immediate cause of indoor air problems in only four percent of the 223 major buildings investigated by ACVA between 1981 and 1987 (see Table 2). Significantly, in those few cases where high accumulations of ETS have been found, ACVA also has discovered an excess of fungi and bacteria in the HVAC system. These microorganisms usually are found to be the primary causes of the complaints and acute adverse health effects reported by building occupants.

Table 2. ACVA Systems Experience -- 1981 to 1987.

Total building studies	223
Number of square feet	39,000,000
Estimated number of occupants	225,000

Summary of most significant pollutants found:

Major Pollutants in Air	% of Buildings
Allergenic Fungi	34
Allergenic or pathogenic bacteria	9
Glass fiber particles	7
Tobacco smoke	4
Carbon monoxide (vehicles)	3
Miscellaneous gases	2

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VENTILATION AND INDOOR POLLUTION

The fact is that the accumulation of many pollutants is itself a symptom of a more serious problem -- a problem of inadequate ventilation. Medicine teaches us that treating the symptoms simply does not work, one has to go after the cause of the problem.

Improper ventilation can sometimes be carried to extremes. The fresh air dampers were closed completely in over 35% of those buildings studied by ACVA (see Table 3). Three years ago we found a building where the "maintenance engineer" had bricked up the fresh air vents to save energy. In Washington State, one NIOSH investigator of a sick building found heavy duty polyethylene

Table 3. Sick Building Syndrome Causes -- ACVA Experience

Sample Buildings: totalling 39,000,000 square feet		223
Period:		1981-1987
(1)	<u>Poor Ventilation</u>	
	No fresh air	35%
	Inadequate fresh air	64%
	Poor distribution of air	46%
(2)	<u>Poor Filtration</u>	
	Low filter efficiency	57%
	Poor design	44%
	Poor installation	13%
(3)	<u>Contaminated Systems</u>	
	Excessively dirty ductwork	38%
	Condensate trays	63%
	Humidifiers	16%

sheets sealing off the fresh air intakes. It turned out that these had been installed two years earlier to reduce the levels of silica dust being carried into the building from Mount St. Helens. There are also numerous incidences of inadequate ventilation due to hidden blockages inside ducts. Using fiber-optic technology, we have found many classical examples of such where turning vanes, dampers, and reheat coils inside ducts have been totally sealed with massive accumulations of dirt, loose insulation, etc.

Perhaps the most serious problem of ventilation is that there is no effective legislation mandating the uniform use of minimum fresh air requirements. Certainly some authorities do specify ventilation rates at the design stage -- most of these are based on ASHRAE or BOCA standards. However, the major problem is that there is no legislative structure, nor is there a practical policing methodology to ensure that the operators of buildings run their ventilation systems according to such designs.

THE EFFECT OF ENERGY CONSERVATION

Some of these examples of inadequate ventilation were due to ignorance or accidents, however, the complex of symptoms that I have mentioned -- the "sick building syndrome" -- may result primarily from energy conservation efforts to seal buildings and reduce the infiltration/exfiltration of air. Such efforts have reduced the natural infiltration of fresh air that previously existed in many buildings, exacerbating the often undiscovered problem of a poorly designed or maintained HVAC system.

In addition to tightening buildings and sealing windows, building managers have shut down air conditioning systems at night and on weekends in an effort to lower energy costs. When the air conditioning is shut down in humid climates, condensation builds up and settles inside the ductwork. If dirt is present in damp ductwork, spores and microbes can flourish, only to be spread throughout the building once the HVAC system is turned on the next morning. This often results in Monday morning complaints of building odors or building sickness that disappear during the week, only to recur the following Monday morning. To save more energy, automatic temperature controllers are used to cycle fans on and off during the day. Vibrations from the start-up of these fans can cause dirt and microbes trapped inside ductwork to be dislodged and carried into occupied areas.

Another energy conservation effort that may contribute to sick building syndrome is the recirculation of indoor air, at the expense of fresh outdoor air. The 35% of the buildings mentioned above were saving energy by shutting off all the fresh air.

Extremely bad distribution of air throughout the building is common, especially in those systems using multiples of fan coil units mounted throughout the various floors of the building. Local thermostats switch off individual units independently of others and micro-environments are set up. Often it is necessary to ensure that when the heating or cooling is not required, all the fans should be left running to aid circulation throughout the areas concerned.

Variable air volume systems (VAV) using VAV mixing boxes mounted in the ceiling void frequently have louvers opening into the void. When certain temperature conditions are met, the louvers open and return or exhaust air from the void can be induced into the supply air, bypassing the filtration system. We have found fiberglass, asbestos, fungi, and ETS to be recycled throughout an office due to this design.

More and more frequently one finds the following design condition, exhaust fans rated at say 70 to 80% of the supply fans. The supply fans are often automatically throttled back for energy savings, say to 25% of their rated capacity. If the exhaust fan is not adjusted at the same rate the exhaust fan can overpower the supply fan and no fresh air gets into the building. The open fresh air louvers now act as addition exhausts and the whole building runs at negative pressure. When this occurs, unfiltered outside air infiltrates into the building or, worse still, exhaust fumes are sucked up from underground garages.

In addition, as described above, the substitution of low cost, low efficiency filters to reduce pressure drops and save energy seriously reduces the efficiency of building filtration systems, and can lead to serious indoor air quality problems.

VENTILATION COSTS

Without doubt, the major resistance to increasing ventilation rates has been the cost of such increases. Most companies have incorporated energy management problems and new operating budgets based on saving every energy dollar possible. In fact, the very salaries and bonuses of building engineers or energy managers are dependent on reduced costs. It would be an anathema for them to consider increasing energy usage and cost by increasing ventilation.

However, forward thinking companies should look way beyond the constraints of budgets of the energy managers. Consider the following; the average heating, ventilation, and air conditioning operating costs of a typical 100,000 square foot building in the Washington, D.C. area would be $50,000 per annum. A commendable target for energy saving by saving on ventilation may be say 25% savings, giving a useful $12,500 per annum. Of course, many of you present

operate buildings many fold larger than 100,000 square feet, so these savings are an attractive goal (see Table 4).

Table 4. Energy Conservation.

Consider a 100,000 square foot building
Typical total utilities cost ($1.25 and $1.75/sq ft)
Average: $1.50/square foot = $150,000 per annum

Typical HVAC fraction (25% to 40%)
Average: 33% = $50,000 per annum

Thus: All energy conservation steps by
reducing ventilation, increasing air
recirculation, etc. contribute a
fraction of $50,000 per 100,000 square foot
Note: a 25% energy savings = $12,500 per year

Now, consider the payroll costs for people in that building. Using typical averages, there are 150 square feet of space per employee, therefore each 100,000 square feet would house 667 people. Supposing we paid these staff only $15,000 per annum for the salary plus payroll costs, the salary bill (667 x $15,000) would be approximately $10,000,000 per annum per 100,000 square feet. Thus, each 1% absenteeism costs $100,000 per annum (see Table 5). Typical absentee rates run at 3 to 7% and no less than 30 to 50% of all absenteeism is estimated to be due to upper respiratory problems. How many of these are due to dusts, bacteria, fungi, fibers, chemicals, ETS, carbon monoxide, oxides of nitrogen, etc., i.e., how many are due to these internal pollutants.

Table 5. Payroll Costs.

Consider 100,000 square feet
Average staffing = 150 square foot/employee
$\frac{100,000}{150}$ square feet = 667 employees

Assume average salary and benefits = $15,000 per annum
667 x $15,000 = $10,000,000 per annum
i.e., each 1% absenteeism costs $100,000 per annum

Note on Averages: Upper respiratory complaints =
30 - 50% of all absenteeism

In short, what does it profit a company to save $12,500 in energy savings if that small saving causes potentially hundreds of thousands of dollars in absenteeism, not to mention lost worker efficiency. Small wonder that some European countries, including Denmark, West Germany, and Switzerland have introduced legislation mandating that steps must be taken to prevent the buildup of internal pollutants. The United States is destined to follow that course either by slow evolution or legislation will be precipitated as a result of court actions brought by individuals or by trade unions making the building owners, architects, designers, and operators responsible for the health and welfare of their staff or tenants.

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